

Efficiency of calcined kaolin and silica fume as cement replacement material for strength performance

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Introduction

The cementing efficiency factor k of a pozzolan is defined as the number of parts of cement in a concrete mixture that could be replaced by one part of pozzolan without changing the property being investigated, which is usually the compressive strength. This concept was proposed by Smith [1] and was initially applied in rational proportioning of fly ash concrete by using the “fly ash cementing efficiency k ”, defined such that a mass f of fly ash would be equivalent to a mass kf of cement in terms of strength development. Compressive strength is normally used as basis for the estimation of k value because it is a simple and a consistent industrial test and, moreover, can be used fairly well to assess the general quality, durability and performance of a particular concrete mixture. In essence, k is a factor that accounts for the difference between the contribution of Portland cement and fly ash to strength development.

Smith's model was in the form of $W/CM = W/(C + kFA)$ where k is assumed to be unique for each fly ash. The k factor is calculated by equating the W/C of Portland cement concrete to the W/CM of Portland cement–fly ash concrete, with the condition that the two concretes have the same workability and the same 28-day compressive strength. Results from Smith's experiment show that a constant k factor for a particular fly ash does not exist; however, a k value of 0.25 was suitable for use in preliminary mixture

proportion of mixtures with up to 25% fly ash. Nevertheless, this method has been reported to be complicated for practical purposes [2].

The efficiency concept, which was initially developed for fly ash, can be easily applied to other supplementary cementitious materials as well, such as silica fume (SF), slag and natural pozzolans. For example, previous studies [3,4] found that the efficiency of SF for compressive strength varies between 2 and 5 for replacement in the range of 5% to 20% of cement by SF. The much higher k value for SF, in comparison with fly ash, is attributed to its high amorphous silica content, as well as its high surface area. Babu and Rama Kumar [5] attempted to quantify the 28-day cementitious efficiency for ground granulated blast furnace slag (GGBS) in concrete at various replacement levels. Their evaluations found that the overall strength efficiency factor varied from 1.29 to 0.70 for 10% to 80% GGBS contents.

2. Review of efficiency models

In 1993, Babu, Rao and Prakash [6] undertook an extensive investigation for different pozzolans and proposed methods for the estimation of efficiency and subsequently applied these factors in the mix design for concretes containing mineral admixtures. They proposed an “overall efficiency factor k ” for a pozzolan that may be assessed via multiplication of two separate factors, the “general efficiency factor k_e ”, which is a constant for all percentages of replacement and the “percentage efficiency factor k_p ”, which varies with the replacement level. The authors subsequently used the model to assess the efficiency of concretes containing fly ash, SF and GGBS. It was found that the overall efficiency factor might change with age, cement type and content, curing conditions and temperature.

In 1995, Hassaballah and Wenzel [7] proposed a

strength-based method to obtain the k value for fly ash. This method is based on comparing the compressive strengths of two concrete mixtures having the same workability. The first mixture contains cement and fly ash, while the second has the same cement content as the first, but no fly ash. If the two mixtures have similar workability, then it is expected that the 28-day compressive strength of the blended mixture (f_c') will be more than that of the second mixture (f_c). Therefore, the total contribution of fly ash to the compressive strength is the difference between f_c' and f_c . The authors then defined the ratio of this difference to the strength of control mixture (f_c) as the pozzolan efficiency factor ($k = (f_c' - f_c) / f_c$). Hence, according to this method, positive k values indicate strength improvement while negative values indicate strength loss.

More recently, Papadakis, Antiohos and Tsimas [8,9] proposed a method to evaluate the efficiency factor for various natural and artificial pozzolans by using the concept of pozzolanic activity index. Pozzolanic activity was determined as the ratio of strengths, of a pozzolanic mortar to that a control mortar. The authors correlated the k value with the active silica content of the supplementary cementitious materials, and an analytical relationship was obtained. By experimental comparison, it was concluded that these expressions are only valid for artificial pozzolans, while for the case of natural pozzolans, the k value is overestimated.

3. Proposed model to evaluate pozzolan efficiency

Conventionally, the efficiency factor for strength performance of a pozzolan is calculated on the basis of comparison between concrete strength and the W/C ratio for a nonblended mixture and between concrete strength and W/CM ratio for a blended mixture. However, this method can be rather complicated for practical application because it requires an extensive set of data to establish beforehand, a relationship between strength and W/CM ratio for different

amounts of a particular pozzolan.

In this paper, a relative strength-based method to obtain efficiency values for strength performance is used. The first mixture is the OPC control mixture, while the second is a blended mixture containing a pozzolanic material as a partial replacement for cement. The total cementitious materials content and other mixture characteristics, such as water and aggregate contents, are the same for both mixtures. In addition, both mixtures are subjected to similar curing history. Therefore, strength development for the control is principally dependent on the rate of cement hydration, while for the blended mixture, is dependent on the combination of cement hydration and pozzolanic reaction. By observing the relative strength, which is defined as ratio of strengths of the blended mixture to the control, an understanding of the rates of reaction in a blended pozzolanic system relative to the control system can be achieved. If the pozzolan contributes positively to strength development at a certain age, then the resulting relative strength value will be greater than unity.

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